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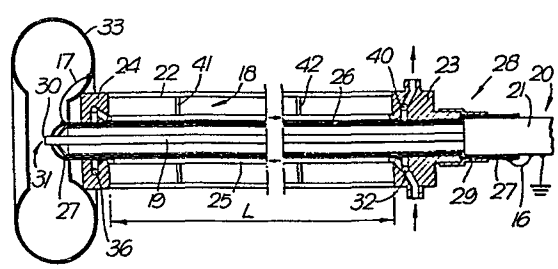
(54) High voltage insulator.

(57) A high voltage insulator (5) is designed to give an even electric field distribution over the insulator. To this end there are arranged high resistive paths (7, 25) within the insulating body (6, 22). These resistive paths are connected to the conductors which are to be insulated. To remove heat generated in the high-resistive paths from the insulator, the insulating body (6, 22) and/or the resistive path (7, 25) material is a fluid (liquid or gas). Preferably both the insulating body and the high resistive paths consist of liquids, and the liquid in the resistive path is preferably pure, de-ionized water which circulates, through an external pumping-, cooling-, and de-ionizing unit (50). The insulator according to this invention is particularly applicable for test terminations when testing high voltage cables (20) with DC.

Fig. 5.



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HIGH VOLTAGE INSULATOR

This invention relates to a high voltage insulator designed to obtain an even distribution of the electrical field between at least two conductors with different electrical potentials, and in particular to a high voltage insulator designed to be used as a test termination equipment for a high voltage power cable.

The very first approach when two conducting elements having different electrical potentials are to be mutually insulated, is simply to arrange an insulator therebetween. The material in this insulator should have as perfect insulating properties as possible.

For high potential differences (say more than 100 kV) or high voltages, this first approach will, however, introduce new problems, more of practical than of a theoretical nature.

All insulating materials, no matter how well prepared they are, have some small, inherent irregularities or impurities when their microstructure is considered. At all such irregularities there will, when a strong electrical field is applied, develop corresponding irregularities in the electrical field. Therefore, local field strength maxima will occur and a break-down process will start and develop if the local peak values of the field strength exceed the limits set by the insulation material. As a matter of fact irregularities in the surroundings will also cause severe field inhomogenties at high voltages, and the behaviour of a close to ideal insulator is therefore unpredictable.

Due to such problems it has already been proposed to insert high resistance paths in insulators to control the field strength at each point along the insulator.

Such a solution is e.g. proposed in British Patent No. 1,068,219. There a semiconducting tape is wound around an insulator at its surface, primarily to avoid corrosion at the surface.

It was also previously known to introduce semiconducting layers at local places to reduce electrical stress. Reference may be made to British Patent No. 1,371,006 and Norwegian Printed Application (NUS) No. 144,003.

However, if such semiconducting layers are subjected to currents passing therethrough, they will be damaged due to the heat generated. Therefore, these solutions are only appropriate for relatively small voltages or the semiconducting layers do not represent a current path at all, but only a screen.

To obtain a good insulation on cable joints or cable terminations it is also known to use housings filled with an insulating fluid. In this connection British Patent No. 1,139,016 and 1,251,341 may be referred to. In accordance with these, however, ordinary stress cones or capacitor windings are used to distribute the field.

More information about these two last mentioned approaches may be obtained from British Patent No. 1,277,792 and US Patent No. 3,312,774 respectively.

Generally speaking, all the earlier methods for insulating extremely high voltages (e.g. up to 2 MV DC voltage) are time-consuming and require skilled personnel as well as much available space.

When e.g. a high voltage terminal has to be built up at a DC power cable end, the following precautions have to be taken in the case of a conventional condenser tape termination.

The cable end must be extremely straight. It may not be moved after tape is applied, as this would result in internal tape movements which would make the termination inferior. Therefore, the cable end has to be arranged at its final test position before the condenser tape is applied and the cable end has also to be positioned exactly at the test location. A scaffold must be built up around it and the cable end must be prepared by dismantling and stripping. Then the insulator has to be built up around the exposed cable core and the workers have to stand on the scaffold in awkward working positions. To prepare one cable end for testing requires approximately 2 men for 2 weeks. During all this time the test plant is occupied by the cable.

The problems may differ according to the cable types which are to be tested, but the example above is realistic when a power DC cable with oil-insulated paper and an outer lead sheath is concerned.

The object of the present invention is, therefore, to provide an insulator which is applicable to extremely high DC voltages, say up to 2 MV, which is easy to install, which gives a good control over the voltage distribution (electrically speaking an extremely "stiff" insulator), and which is easily adaptable to different insulating purposes e.g. to different types of cables.

According to the invention in its broadest aspect there is provided a high voltage insulator designed to obtain an even distribution of the electric field between at least two conductors with different electrical potentials, which insulator comprises at least two different components, namely a substantially ideal insulating body and at least one highly resistive (also called semiconducting) element having a small cross-sectional area, these components being connected to the conductors, characterised in that the insulating body and/or the semiconducting element(s) comprise(s) a fluid (liquid or gas) which enhances the conduction of heat from the semiconducting element(s).

By using an insulator according to the present invention there is obtained: a very good, smooth and controllable voltage distribution over the insulator, a smooth and easily controllable temperature surveillance, an easy-to-mount and easy-to-adapt insulator, a new design which may be used at much higher voltages than present solutions, as generated heat may be conducted out of the system.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 shows the main principle of the invention;

Figs. 2-4 show different embodiments of the invention;

Fig. 5 shows a preferred solution for a power cable termination equipment according to an embodiment of this invention, and

Fig. 6 shows the arrangement for testing a high voltage cable with an insulator according to an embodiment of this invention.

In Fig. 1, 1 and 2 are two electrical conductors having different potentials, here denoted as + and -. These are only to be understood as relative values, as one of the conductors may be grounded. The distance L between the conductors must of course be so large that a direct flash-over through the ambient medium is avoided.

Each of the conductors is connected to a connecting member 3 and 4. These connecting members are good conductors, preferably of metals as copper, aluminium or the like. They are here shown with a smooth, rounded off surface to prevent corona.

Between the connecting members is arranged an insulator 5 according to the present invention.

The insulator comprises two different portions, the insulating body 6 and the high resistance path(s) 7 embedded therein. If the high resistance path(s) was (were) not included, the electrical field would have a random distribution caused by occasional disturbances. When the high resistance path(s) is (are) included this (they) will, however, ensure an even field distribution along the insulator. This is shown in Fig. 1 A.

If we now select the materials in the insulating body and the high resistance path(s) as solids or fluids, and also try to introduce a cooling effect in the insulator, the following possibilities are present:

TABLE I
PRINCIPLES OF INSULATOR DESIGN

Insulating body	High resistance path(s)	Cooling method	
solid	solid	outside agent	
fluid	solid	insulating agent	possibly also an outside agent
solid	fluid	resistive agent	
fluid	fluid	any agent or both	

As table shows:

If both the insulating body and the high resistance path(s) (one or several) is made of a solid material, it is necessary to let the insulator be cooled by an outside agent, which may e.g. be water in a cooling hood (not shown) or simply ambient air flowing alongside the insulator's surface. This is, of course, known technique.

If however, the insulating body 6 consists of a fluid (enclosed in an insulating housing) while the high resistance path(s) 7 is (are) built up from solid matter, e.g. thin metallic wires or a metallic substrate on the inner surface of the insulating housing, then the cooling may be effected by the insulating fluid itself. The insulating fluid may even circulate through an externally arranged heat exchanger. Some different solutions are principally shown in Figs. 2, 3 and 4 respectively. Here the same designation numbers are used as in Fig. 1, but in addition 8 is a housing of a fluid (liquid or gas) insulating agent, and 9 designates insulating conduits containing a high resistance fluid.

As seen in the Table I the insulating body may be made from a solid matter while the high resistance path may consist of a fluid. It will be self-explanatory how the insulator then acts.

Finally both the insulating body and the high resistive path material may be fluids. One or both may then be active as cooling mediums, either in a system with no external circulation, that is with only heat exchange and dissipation, in the Fig. 1 embodiment, or with a system in which at least one of the mediums is circulated, possibly through an externally arranged heat exchanger. This is shown in the figure 2 (only insulating fluid circulates to the external cooling device), Fig. 3 (only high-resistive fluid circulates to the external cooler and deionizer), and Fig. 4 (both fluids circulate).

All the three combinations mentioned in the lowermost lines in table I are within the scope of the present invention. However, the very last embodiment is believed to provide the best solution, and then preferably with a closed, non-circulating insulating agent, but with a circulating high-resistive agent in the tubes 9. That is the principle shown in Fig. 3. The tubes 9 may preferably be of insulating material, but they may then preferably be broken at the point of intrusion into the connecting members 3 and 4. Thus the high resistance fluid will be in direct electrical contact with the conductors 1 and 2.

If an insulator according to these principles is to be used in a testing equipment for high voltage power cables having an outer screen, it may be built up as shown in Fig. 5.

The cable 20 shown in this figure may be a single conductor power cable for DC, e.g. with an impervious sheath 21 of Al or Pb. This metal sheath 21 is stripped off for a length L of the cable core, which length depends on the test voltage applied as mentioned in connection with Fig.1.The exposed cable core is then brought into the tube shaped insulator 22 according to this embodiment.

The insulator comprises: an outer insulating housing 22, a lower flange 23, an upper flange 24, insulating tubes 25 for a highly resistive fluid.

To prepare the cable end for testing the following steps are undertaken. All these steps are undertaken while the cable end is in a proper working position and height. The outer protective and screening sheaths are removed at a length L. If the cable has an impregnated core, a heat shrinking sleeve 26 is applied over the exposed core portion. The cable insulation is not removed from the core. This procedure simplifies the operation considerably and also provides an effective seal in a simple manner. A semiconducting tape 27 is applied both at the core end and at the screen end 28.

The cable end is quite simply brought into the insulator arrangement, so deeply that the screen end becomes aligned with the lower flange 23 and the core end becomes aligned with the upper flange 24. Then the lower flange 23 is secured in a sealing manner to the outer screen of the cable at 28, and also to the semiconducting tape winding 27, e.g. by means of a shrinkable sleeve 29.

The cable conductor 30 is secured to the upper flange 24, and the semiconducting windings 27 as well. If an oil-filled cable is considered, the oil channel 31 is connected to an oil chamber to feed the cable end with oil.

The insulator is brought into correct test position by lifting and tilting.

The interior 18 of the housing 22 is filled with a suitable insulating fluid. Silicone oil is preferred due to its non-flammability. SF_6 gas may also be used as a practical fluid.

The tubes 25 are filled with a high resistance agent. Purified and de-ionized water is preferred. The tubes 25 may be connected to an externally arranged unit 50, Fig. 6 for circulating the water (via a pump) to cool the water (by means of a heat exchanger) and for de-ionizing the water in a de-ionizer. This external unit does not in itself represent a part of the invention. It may be manually controlled or automatically monitored. Parameters which may be changed or monitored are velocity of resistive agent, temperature of resistive agent, quality of resistive agent etc. In a prototype, the following values were used; 6 pipes with internal diameter of 13 mm Ø were guiding de-ionized water. The pump was circulating approx. 10 l/min. The test voltage applied was 1,5 MV. A conventional ion-exchanger was used.

As mentioned above, the insulating agent may also be circulated or its quality may be monitored.

But in this preferred embodiment the insulating agent is not circulating.

The connection to high test voltages is finally obtained in a conventional manner, e.g. screened by a conducting toroid 33 to reduce corona.

The mounting of a test arrangement according to the present invention may easily be finished in a few hours, and it may be undertaken in a corner of the test site. If the cable end together with the insulator is arranged on a carriage with adjustable height and adjustable tilting, a very convenient plant is obtained.

In Fig. 5 some further details of the insulator are shown. The branched tube 32 is an input manifold for the high-resistive fluid which passes through the tube(s) 25 (preferably three parallel tubes) up to an upper manifold section 36. Here the fluid is distributed and passes back to the lower flange 23 through the upper tube(s) 25 (preferably also three parallel tubes). Finally the high resistance fluid leaves the insulator through manifold 40, and passes to an external pump, de-ionizer and purifier unit (50, Fig. 6).

Distance rings 41, 42 are arranged at intervals to keep the tube(s) 25 in position.

The manifolds 32, 36, 40 are made from metal and thus the fluid has direct contact with their internal walls. The manifolds are also electrically connected to the flanges (23, 24, Fig. 5).

In Fig. 6 the cable end with an insulator box according to this invention is arranged on an adjustable framework 43. The mounting is undertaken when the cable end is in its lower position, and when testing is to be undertaken the framework lifts and tilts the cable end to its upper position in which the test is undertaken.

This equipment is particularly suitable for test purposes. A test termination according to the present invention is easy to mount/demount and easy to adjust to different test parameters. A test termination is arranged as a rule at indoor locations where the different parameters are easy to adjust. However, some embodiments of this invention may also be suited for field application.

By adjusting the temperature of the de-ionized water, the resistivity is also adjusted. But the pipe dimensions may also be altered to adapt the test termination to other voltages.

The insulating device may, if desired, be built up from transparent materials and thus the interior of the insulator may be visually supervised during the process.

Distance rings 41, 42 as shown in Fig. 5, are not always necessary, only if the stripped cable core portion has to be extremely long due to high test voltages. However, other solutions may be used as well, e.g. a hollow, double walled sheath or the like. The only essential factor is that strings or streams of highly resistive fluid are guided alongside the conductor in the interior of the insulator. The highly resistive fluid may only circulate internally in a closed tube system, either due to thermal changes or due to an active pump. However, the fluid may also only flow through the system to an exhaust output. The number of the tubes or pipes with highly resistive fluid is not critical. It is assumed that the distance between two adjacent tubes should preferably be inversely proportioned to the electrical field strength. In the shown cable test application therefore the distance is constant as the field strength is constant in each cross-section.

If the highly-resistive fluid is water as suggested, the conductivity may be adjusted by adding different additives, or by adjusting the temperature. Thus the same dimensions may be used in the equipment for rather different voltages.

CLAIMS:

1. High voltage insulator (5) designed to obtain an even distribution of the electric field between at least two conductors (1, 2) with different electrical potentials, which insulator (5) comprises at least two different components, namely a substantially ideal insulating body (6) and at least one highly resistive (also called semiconducting) element (7) having a small cross sectional area, these components (6, 7) being connected to the conductors, characterised in that the insulating body (6) and/or the semiconducting element(s) (7) comprise(s) a fluid (liquid or gas) which enhances the conduction of heat from the semiconducting element(s).

2. High voltage insulator according to claim 1, characterised in that the insulating body (6) consists of an encapsulated insulating fluid while the semiconducting element(s) (7) consist(s) of string(s) and/or sheath(s) of a solid semiconducting material.

3. High voltage insulator according to claim 1 or 2, characterised in that the insulating body (6) may be either an insulating fluid, an insulating gas or an insulating solid, while the semiconducting element(s) (7) consist(s) of a high resistance fluid, possibly arranged within insulating pipes (9) or (a) double walled sheath(s) arranged in the interior of the insulating body.

4. High voltage insulator according to claim 1, 2 or 3, and in particular designed to be used in a test termination equipment for a high voltage cable (20), provided with at least one axially arranged conductor in the core and at least one outer, conducting sheath, e.g. an impervious lead sheath (21), which cable during a test procedure is provided with a very high test potential difference between the conductor(s) and

the conducting sheath, and in which the conducting sheath(s) before the test procedure is (are) stripped off from the cable end so that a certain length (L) of the cable core is exposed, characterised in that the insulator comprises an oversized hollow insulating body (22) adapted to be arranged around the exposed portion of the cable core, at least one semiconducting element (25) (string or sheath) embedded in said insulating body, a conducting flange (23, 24) arranged at each end of the hollow insulating body, each flange (23, 24) being electrically connected to the semiconducting element(s) and also to the conducting sheath end (28) and to the conductor end (30), respectively.

5. High voltage insulator according to claim 4, characterised in that the insulating body comprises an outer insulating oversized tube (22) arranged around the exposed cable core (19), leaving a considerable space between the cable core and the internal surface of the oversized tube, and that this space is filled with an insulating fluid (18), preferably a non-flammable fluid such as silicone oil or SF_6 gas, and that the semiconducting element(s) (25) is (are) arranged in the space and at each end is (are) electrically connected to the flanges.

6. High voltage insulator according to claim 4 or 5, characterised in that the semiconducting element(s) is (are) (a) fluid contained in at least one insulating or into a coaxially arranged double walled tube.

7. High voltage insulator according to claim 3, characterised in that the fluid which makes up the semiconducting element(s) (25) is circulating in the pipe(s) or tube(s) and preferably also through openings or channels arranged in the conducting flanges.

8. High voltage insulator according to claim 6 or 7, characterised in that the fluid which makes up

the semiconducting element(s) is pure, de-ionized water circulating in a closed system incorporating a de-ionizer and a heat exchanger and a pump.

9. High voltage insulator according to claim 6, 7 or 8, characterised in that the circulating fluid enters and leaves the insulator through openings in the same flange (23), preferably the flange which lies at the lower electrical potential, while the other flange (24) is designed as a manifold for distributing and returning the fluid flow.

10. High voltage insulator according to claim 6, 7, 8, or 9, characterised in that the tube(s) or pipe(s) for the fluid semiconducting medium is (are) interchangeable with tubes or pipes having other dimensions.

11. High voltage insulator according to any one of claims 4-10, characterised in that the semiconducting elements (7, 25) are evenly distributed along the circumference of the cable core (19) or over the area of the insulator (6).

12. High voltage insulator according to any one of claims 4-11, characterised in that the semiconducting medium is monitored and controlled to maintain a predetermined temperature range.

13. High voltage insulator according to any one of claims 4-12, and where the insulating body comprises an insulating fluid, characterised in that the fluid is arranged between an outer, hollow, insulating tube and an inner, shrinkable, insulating hose, shrunk directly onto the cable insulator, and that a sealing gasket joins the tube and the hose at least at the lower end of the stripped off cable portion.

14. High voltage insulator substantially as described with reference to the accompanying drawings.

Fig. 1.

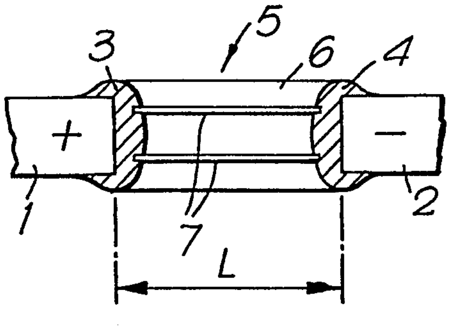

Fig. 1A.

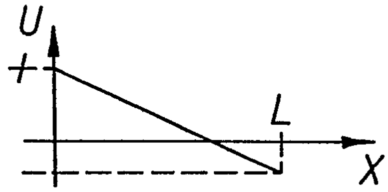

Fig. 2.

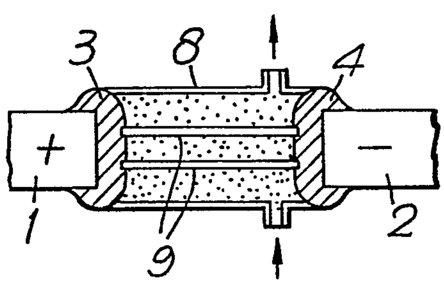

Fig. 3.

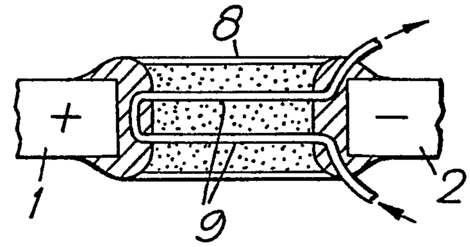

Fig. 4.

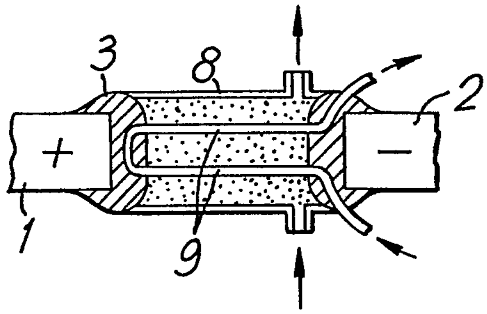

Fig. 5.

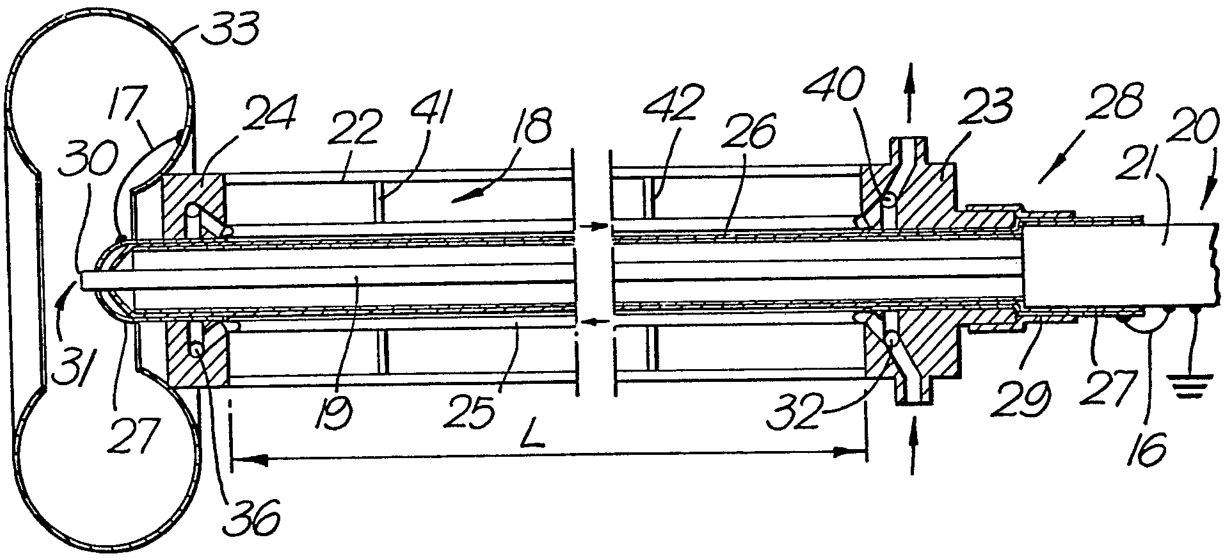
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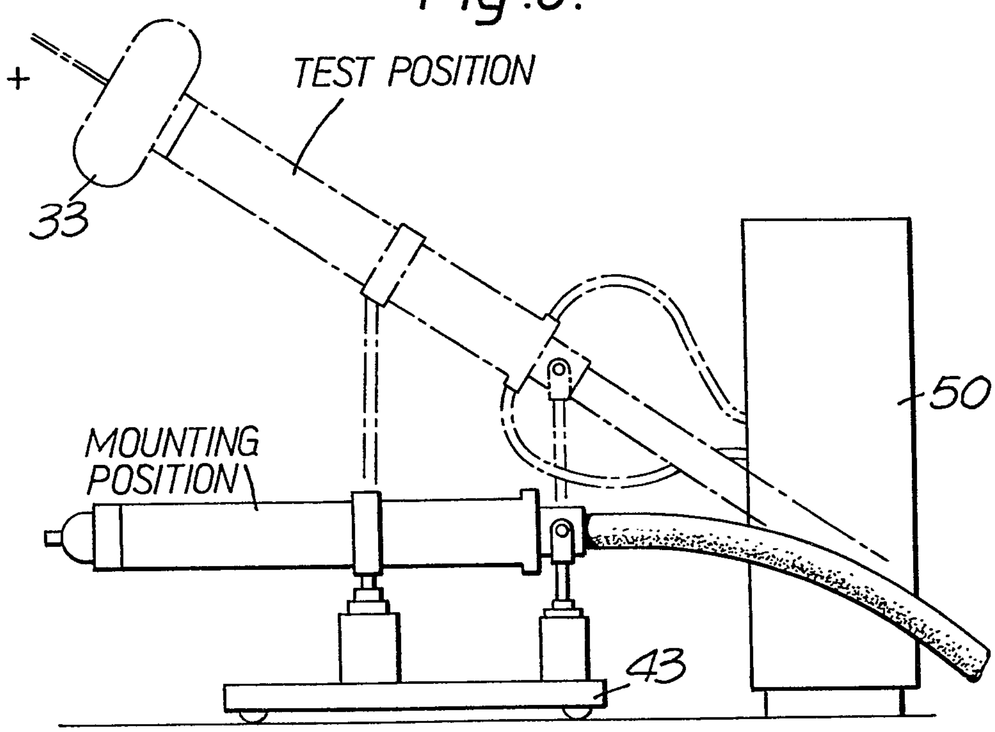
Fig. 6.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